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Reduction of the Rise Time Delay for Pulsed Current of Glow-Discharge-Driven Inertial Electrostatic Confinement Fusion Device

グロー放電式 IEC のパルス電流立ち上がり時間の遅れの改善

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A pulsed Inertial Electrostatic Confinement Fusion Device (IEC) has been developed to extend its application. We observed that the rise in glow-discharge current was delayed and the delay time depended on gas pressure and cathode voltage. We also investigated the relationship between the current and voltage of the glow-discharge in high current region. Based on these experimental results, modification of the external circuit is discussed to shorten the delay time.

1. Introduction

Inertial Electrostatic Confinement (IEC) fusion is recognized as a useful scheme for neutron source. Ions are accelerated toward the spherical center with high voltage applied to a cathode, resulting in fusion reaction [1]. Most of IEC devices has been operated using DC power supplies so far. It is important to develop pulsed IEC devices to extend their application. One of such an application is active interrogation of U-235 to block smuggling [2].

An issue to be coped with in pulsing the neutron yield in an IEC is that, in an earlier work, the rise in glow-discharge current was seen to be delayed considerably, and it was found that the delay time was dependent on gas pressure [3]. However, it is not elucidated how the delay time depends on the gas pressure. In this study, we investigate the dependence of the delay time on gas pressure and applied voltage. In the earlier works, the DC IECs have been operated with the discharge current on the order of mA. We investigate the I-V curve of glow-discharge in high current region on the order of A using pulsed IEC. Based on these experimental results, we then discuss modification of the external circuit in order to shorten the delay time.

2. Experimental setup

The system in the present experiments is composed of, a 100kV DC power supply, a pulsed high-voltage (HV) generator and an IEC device, as shown in Fig.1. The pulsed HV generator consists of a capacitor, a current-limiting resistance, and two semiconductor HV switches. Figure 2 shows typical pulse waveforms of discharge voltage V_d and

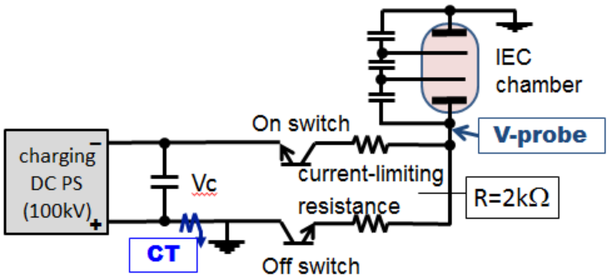

Fig.1 Electrical circuit of the pulsed glow-discharge-driven IEC and high voltage pulse generator

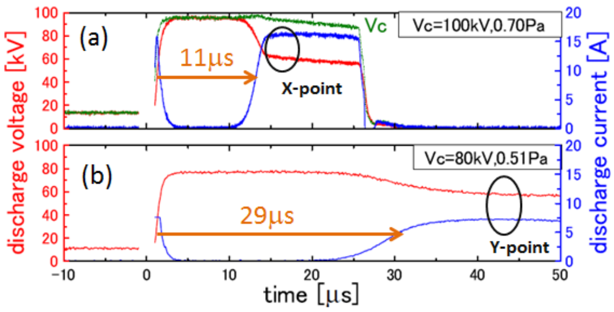

Fig.2 Typical waveforms of pulsed discharge

discharge current I_d, with different gas pressures and applied voltages. When the on-switch is turned on at t = 0, the cathode voltage V_d rises up toward the voltage applied to the capacitor. Then the discharge current I_d starts rising several tens μsec after the voltage is applied to the IEC cathode. V_d then decreases as the I_d increases, because of the following relation;

$$V_c = V_d + RI_d \quad (1)$$

where V_c, R and I_d respectively denotes charging voltage, current-limiting resistance and current measured by CT. The charging voltage, V_c, in Fig.2

(a) is derived from Eqn. (1).

After the current reaches a peak value, the discharge current and voltages, V_c and V_d, gradually falls down during grow discharge since the capacitance voltage drops down. When the on-switch then opens, the off-switch is turned on successively, and as the result, a discharge current and discharge voltage fall down in a few μsec.

3. Experimental Results

We define the time constant, τ, of the rise in glow-discharge current. As a result of having experimented, it is found that it is correlative in the time constant τ and the delay time Δt as follows;

$$. \Delta t = 8.5 \tau \quad (2)$$

This is to imply that the discharge current is low so as not to be able to measure in region to 10 μs from 0 μs of Fig.2 (a), but the discharge current rise up with a correlation of τ and Δt. We define the charging voltage, V_{c0}, as the voltage where the current does not seem to rise up. Because most of the delay time is in this region, Δt depends on V_{c0}.

Figure 3 shows the relationship among the growth rate, γ, gas pressure and charging voltage V_{c0}. The growth rate γ is given as follows;

$$\gamma = 1/\tau \quad (3)$$

The growth rate γ increases linearly with P in Fig.3 (a). The reason why γ depends on P is that the collision rate between deuterium ions and background gas increase with increasing gas pressure. And, the growth rate γ increases linearly with V_{c0} in Fig.3 (b). The reason why γ depends on V_{c0} is that the cross section of ionization by deuterium ions increase with increasing V_{c0}.

4. Discussion

Figure 4 shows the I-V curve of the glow discharge. An issue is that the delay time is too long at below the rated current. We investigate the X-point where the discharge current is the highest experimentally in this study, and the Y-point where the discharge voltage is the same as that at the X-point. The X-point on the <1>-line is shown in the pulse waveforms in Fig.2 (a). The <1>-line is determined by Eqn. (1). The operation at X-point is possible in acceptably short delay time, but the pulse current is higher than the rated current. The Y point on the <2>-line is shown in the pulse waveforms in Fig.2 (b). The current at the Y-point is lower than the rated current, but the delay time is considerably longer than that at X-point.

One possibility to shorten the delay time is to modify the external circuit at below the rated current. Changing current-limiting resistance into

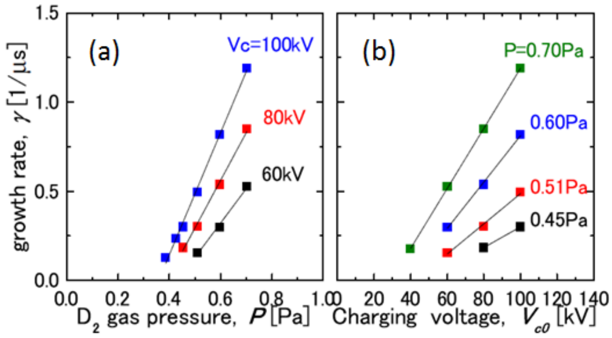

Fig.3. Growth rate (γ) of discharge current against deuterium gas pressure and the charging voltage where the current does not rise up

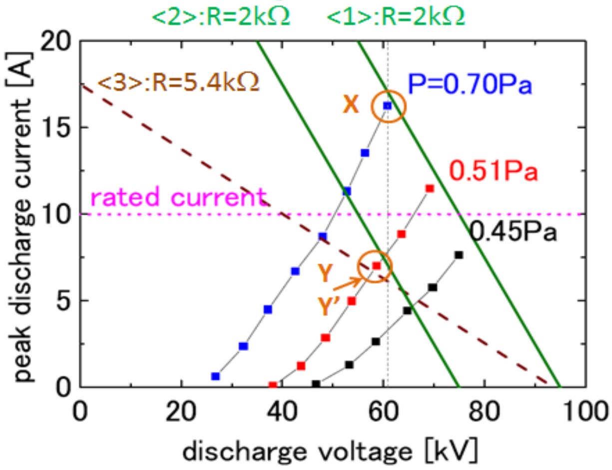

Fig.4. I-V curve of glow discharge at some gas pressure condition

R=5.4kΩ may make the <1>-line moves to the <3>-line, and the X-point on the <1>-line moves to the Y-point on the <3>-line where the discharge voltage is the same as that at the X-point. This point is expressed with Y'-point. Because the growth rate γ depends on V_{c0} in Fig.3 (b), γ of the Y'-point is expected to be 0.49 [1/μs]. The delay time Δt would be 17 μsec from Eqns. (2) and (3). Although Y'-point and Y-point are the same operation points, it seems that there are 12 μsec difference in the delay time between Y'-point and Y-point.

5 Conclusions

We have experimentally studied the dependence of the delay time in discharge on gas pressure and charging voltage in the pulsed IEC. We obtained the I-V curve of the glow discharge in the high current region. It may be possible to operate at shorter delay time at below the rated current by modifying the external circuit.

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